Joint Decision Between Maintenance Strategy of Heavy Equipment and Production Planning

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Abstract.
Reducing downtime gives a significant impact on productivity growth. Such reduction is a prerequisite for profitable and flexible production. The optimal level of preventive maintenance performed on any system guarantees the cost effective and reliability of the system. A model is developed to integrate maintenance strategy decisions and production planning. Maintenance strategy should be integrated with production planning. The purpose of this study is to identify the factors that influence the heavy equipment maintenance strategy, model the problem of heavy equipment maintenance strategies at PT Vale Indonesia and provide recommendations on win-win solutions from the perspective of heavy equipment downtime and from a minimization perspective maintenance cost. Linear Programming (LP) is used to model the problem situation and then an optimum solution will be proposed. The results of the optimization research found that by setting the composition of the use of three types of maintenance strategy, namely preventive maintenance, planned maintenance and unplanned maintenance, the optimum maintenance cost and downtime can be achieved. The optimization results are used to calculate the production plan to realize a mutually beneficial decision between heavy equipment maintenance strategy and production planning.

Keywords:
Joint Decision, Maintenance Strategy, Heavy Equipment, Linear Programming

1. Introduction

Mining companies need heavy equipment to support the mining process. This heavy equipment is useful to speed up the process and save time, effort, and help do work that is difficult to do manually. Heavy equipment is an investment that is very large in value for the company, for this asset must be managed properly and with proper management as well, so that it can bring maximum results for the company in carrying out its projects and generate profits for the company.

Mining companies want high productivity in carrying out their activities. How fast do we do work like drilling and blasting. How many stones can we fit in one shift. How many tons of ore can we move in a year. Calculating the level of production and the cost of heavy equipment especially dozers seems like a relatively simple thing. In most cases, dozer productivity calculations are based on available literature and equipment specifications published by the manufacturer. Dozer performance evaluations often depend on past experience, best estimates or other factors whose objectivity is difficult to assess. Production and maintenance planning are some of the most common and important issues facing the industry (Xiao et al. 2016).

In traditional maintenance approaches, predefined tasks are performed regularly. This approach is not profitable and does not extend the life of the components for as long as possible (Endrenyi et al. 2001). In previous studies, the preventive maintenance model incorporates a transition from the degradation stage to one type of maintenance state (Chan 1998; Endrenyi et al. 1998). However, depending on the level of deterioration, there is a scope for different levels of maintenance (Endrenyi et al. 1998). This study is intended on how to formulate the best maintenance method so that a method with the most optimal maintenance costs and the minimum downtime can be obtained. This will certainly increase company profits through the achievement of an improved dozer performance compared to calculations based on company history or recommendations. Production and maintenance planning are the most common and important issues in the industry (Xiao et al. 2016). At the end of this case study, a maintenance strategy must be given and the impact on production planning will be given.

2. Mining Activity

The factors that influence the continuity of mining activities are divided into two categories, namely economic factors and technical factors (General Conditions of mining operations, Equipment or equipment needed and Mining Implementation Methods). The main purpose of mining activities is to extract sediment from the parent rock, making it easy to transport and process in the next process. After the mining preparation operation is complete and the overburden removal is carried out, the mining operation can begin.

Mining activity is shown in Figure 1. The stages of mining activities consist of several stages, namely:

a. **General investigation** is the first step aimed at finding deposits of minerals by utilizing geological anomalies in a particular area. Some of the activities undertaken include searching for existing literature, studying satellite maps and geological maps, conducting a preliminary survey of space and processing and analysing the data obtained.
b. **Exploration** aims to find out the geometry, position, quality and quantity of sludge that aims to evaluate the sludge.
c. **Feasibility studies** are stages to assess whether the mining materials are feasible or not to be mined based on technical, economic and environmental considerations.
d. **Mining preparation** is the preparation stage for all kinds of needs for mining including development, land clearing, road construction, and others.
e. **Mining** is the process of extracting excavated material itself, then it is processed and utilized for human life.
f. **Processing of minerals** is the activity of processing minerals by utilizing the physical and chemical properties of minerals to produce valuable products (concentrates) with higher levels of feed and products with no value (tailings) for disposal.
g. **Transportation** aims to move materials from mining activities to other processing or utilization sites.
h. **Marketing** is the activity of selling mining products and mining materials that have been processed/refined.

Figure 1. Mining Activity.

3. Mining Support Equipment

To carry out mining activities, mining companies need equipment that will be used to carry out mining activities. This equipment such as Shovel, Backhoe, Grader, Loader, Dozer, Trailer, etc. The equipment that will be discussed in this case study is Dozer.

Dozer is a crawler type tractor that is equipped with a front blade (also call as pusher blade). Crawler type is a type of wheel a dozer equipped with. And in this type, dozer runs on two endless tracks. Due to crawler type it has a low ground pressure and that makes dozer to work even on those surfaces where normal wheel dozer is unable to work. Dozer is shown in Figure 2. The bulldozer is usually used for:

a. Street cleaners.
b. Opening to the mountain roads or rocky areas.
c. Transferring Land
d. Interesting Scapper.

e. Extend land stuffing.
f. Road Maintenance.

Figure 2. Dozer.

The calculation of dozer production rates, physical availability and the costs of working on dozer operation seems like a simple task. In most cases, this applies to the content and specifications for the device produced by the manufacturer. Dozer performance assessments often plan based on past experience, estimate, or other factors that are difficult to evaluate objectively.

In this paper, an optimum maintenance cost and downtime calculation will be performed using Linear Programming which is more objective than the current method. The Linear Programming Method is expected to produce the most optimum maintenance costs and downtime that will make dozer productivity and Nickle production increases.

4. Mathematical Model Formulation

Various mathematical models have been used to prepare for optimization. In the literature on maintenance optimization models it is stated that "there are a number of case studies published which show that mathematical models are a good means to achieve both effective and efficient maintenance" (Dekker 1996). The relationship of cost elements with the maintenance planning was also explained by Bouslah (2018). In Levitt (1996), it is mentioned that the cost area can be decreased with good maintenance practices are. The mentioned cost element in his book can also be included as the cost model so that the model will be more realistic (Levitt 1996). The proposed mathematical model integrates the preventive maintenance, planned maintenance, and unplanned maintenance in a real maintenance strategy and production.

4.1. Previous Data

Data taken as a reference in this paper is actual data and budget data for three years (2017-2019). The data is summarized in the Table 1.

Table 1. Previous Data.

Variable	Actual	Budget
Maintenance cost	$ 7,105,137	$ 5,926,507
Downtime	39,473 hr	36,816 hr
Physical Availability	79%	85%
Dozer Production	31,867,575 M^3/year	33,901,676 M^3/year

4.2. Conceptual Model

The conceptual model used for this case study is as in Figure 3.

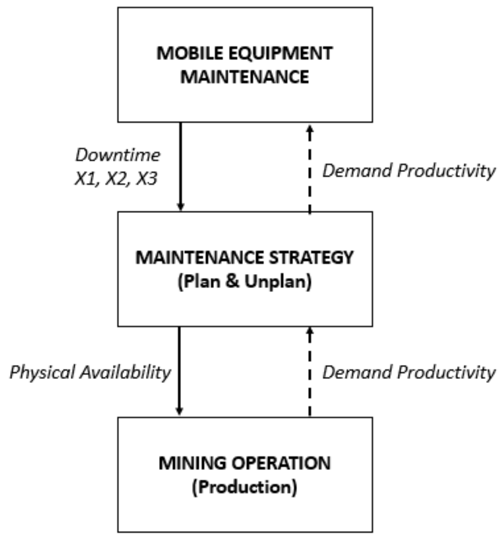

Figure 3. Conceptual Model.

4.3. Notation Used in the Mathematical Model

Parameters

MB	Maintenance Budget
MC	Maintenance Cost
S	Standby time
OP	Operating Hours
MH	Manhours
P	Productivity
R	Maximum Downtime allowed
UoA	Used of Availability
PA	Phisycal Availability
CPH_PV	Cost per hour Preventive Maintenance
CPH_CD	Cost per hour Planned Maintenance
CPH_CR	Cost per hour Unplanned Maintenance
Q	Produksi
M_PV	Manpower for Preventive Maintenance
M_CD	Manpower for Planned Maintenance
M_CR	Manpower for Unplanned Maintenance
R_PL	Downtime of Plan job
R_UP	Downtime of Unplan job

Decision Variables

X_1	Downtime Preventive Maintenance
X_2	Downtime Planned Maintenance
X_3	Downtime Unplanned Maintenance

4.4. Assumptions and Values Used in the Model

a. Average cost per hour preventive maintenance (*CPH_PV*) is 185 $/hr, average cost per hour planned maintenance (*CPH_CD*) is 216 $/hr, and average cost per hour unplanned maintenance (*CPH_PV*) is 139 $/hr.
b. Considered used of availability (*UoA*) = 65%.
c. Standby time (*S*) per year is 73,019 hr.

d. Manpower for Preventive maintenance (*M_PV*) is four employees, manpower for plan maintenance (*M_CD*) is 2 employee, manpower for corrective maintenance (*M_CR*) is two employees.
e. Total number of Dozer is 54 units.
f. Maintenance Budget (*MB*) per year is $ 5,926,507.
g. Dozer Productivity (P) = 250 M^3/hr.
h. Plan operating hours of Dozer (*OP*) is 245,442 hr per year.
i. Plan manhours (*MH*) is 109,620 manhours per year.
j. Plan Phisycal Availability (*PA*) is 85%.
k. Comparison of plan downtime (*PV* and *CD*) and unplan (*CR*) is 80% and 20%.
l. Dozer production capacity (Q) with *PA* = 85% is 33,901,676 M^3/year.

4.5. Model Components

The maintenance cost is most commonly used to measure maintenance performance. For most previous studies, cost minimization was the most common goal of joint optimization for maintenance and other functions (Van Horenbeek 2010). Maintenance costs for large companies represent 40% of the total budget (Levitt 2009; Niebel 1994; Dunn 1998). In the proposed model, we used two major criteria of minimizing the maintenance cost and downtime to optimize the equipment performance.

4.5.1. Objective Function 1: Minimize the Maintenance Cost

$$\text{Min } Z_1 = (CPH\_PV*X_1) + (CPH\_CD*X_2) + (CPH\_CR*X_3) \quad \text{(OF-1)}$$

The following constrains used for this calculation.

$$(CPH\_PV*X_1) + (CPH\_CD*X_2) + (CPH\_CR*X_3) <= MB \quad (1)$$

Constraints (1) is rewritten as Equation (1a) after adding the values for parameters *CPH_PV* [185 $/hr], *CPH_CD* [216 $/hr] and *CPH_CR* [139 $/hr].

$$185 * X_1 + 216 * X_2 + 139 * X_3 <= 5{,}926{,}507 \quad (1a)$$

Constraint (2) defines the total downtime allowed for maintenance.

$$X_1 + X_2 + X_3 <= R \quad (2)$$

Calculation of total downtime is:

$$R = (100\% - PA) * OP$$
$$R = (100\% - 85\%) * 245{,}442$$
$$R = 15\% * 245{,}442$$
$$R = 36{,}816 \text{ hr}$$

So,

$$X_1 + X_2 + X_3 <= 36{,}816 \quad (2a)$$

Constraint (3) restrict manhours is not more than 109,620

$$M\_PV * X_1 + M\_CD * X_2 + M\_CR * X_3 <= MH \quad (3)$$

By adding the parameter values *M_PV* (4 employees), *M_CD* [2 employees] and *M_CR* [2 employees]. Finally, manhours constraint is rewritten as

$$4 * X_1 + 2 * X_2 + 2 * X_3 <= 109{,}620 \quad (3a)$$

Constraint (4) defines maximum downtime for plan downtime

$$X_1 + X_2 >= R\_PL \quad (4)$$

Maximum plan downtime is calculated as

$R\_PL = 80\%*R$
$R\_PL = 80\%*36{,}816$
$R\_PL = 29{,}453$

Constraint (4) rewritten as

$$X_1 + X_2 >= 29{,}453 \quad (4a)$$

Constraint (5) defines maximum downtime for unplan downtime

$$X_3 <= R\_UP \quad (5)$$

Maximum unplan downtime is calculated as

$R\_UP = 20\%*R$
$R\_UP = 20\%*36{,}816$
$R\_UP = 7{,}363$

Constraint (5) rewritten as

$$X_3 <= 7{,}363 \quad (5a)$$

Constraints (6), (7) and (8) define that X_1, X_2, and X_3 are non-negative values.

$$X_1 >= 0 \quad (6)$$
$$X_2 >= 0 \quad (7)$$
$$X_3 >= 0 \quad (8)$$

The above described mathematical model (Model-1) with objective function (OF-1) and constraints (1)–(8) was solved using Lingo solver and the results are tabulated in Table 2.

Table 2. Optimal Values of Model-1.

Objective Function: Z_1 (Minimize Maintenance Cost)				**Unit**
Objective Funtion Value Z_1	5,575,781			$
Decision variables	Downtime Preventive Maintenance	X_1	25,357	hr
	Downtime Planned Maintenance	X_2	4,096	hr
	Downtime Unplanned Maintenance	X_3	0	hr

4.5.2. Objective Function 2: Minimize Maintenance Downtime

The second priority objective function (OF-2) is to minimize the maintenance downtime of three different maintenance category: Preventive maintenance, planned maintenance, and unplanned maintenance. Non-pre-emptive goal programming.

$$\text{Min } Z_1 = X_1 + X_2 + X_3 \quad \text{(OF-2)}$$

Calling this as Model-2, with objective function OF-2 and constraints (1)–(8), solved using Lingo solver. The results are tabulated in Table 3.

Table 3. Optimal Values of Model-2.

Objective Function: Z_2 (Minimize Maintenance Downtime)				**Unit**
Objective Funtion Value Z_2	29,453			hr
Decision variables	Downtime Preventive Maintenance	X_1	25,357	hr
	Downtime Planned Maintenance	X_2	4,096	hr
	Downtime Unplanned Maintenance	X_3	0	hr

4.5.3. Physical Availability & Dozer Production Capacity

A. New calculation for Physical Availability (using Linear Programming result)

PA = (W+S)/(W+S+R) * 100%
PA = (245,442 + 73,019) / (245,442 + 73,019 + 29,453) * 100%
PA = 91.53 %

B. New calculation for Dozer production (using Linear Programming result)

*Q = PO * PA * UoA * P*
Q = 245,442 * 91.53% * 65% * 250
Q = 36,506,123 M^3/year

4.5.4. Sensitivity Analysis

Sensitivity analysis is needed to determine the effect that will occur if the parameters are changed, especially on the objective function and decision variables. In this study a sensitivity analysis was carried out involving all the parameters of the existing models. The parameters analysed for sensitivity are:

a. Cost Per Hour (CPH)
b. Maintenance Cost Budget
c. Downtime Budget
d. Manhours Budget
e. Actual Manpower

The results of sensitivity analysis are shown in Table 4. From the five parameters tested for sensitivity, the sensitive parameters are budget manhours and actual manpower, because in these two parameters the objective function and decision variables can change. However, because the actual parameter of the manpower unit is a person, and the value must be an integer, the change in sensitivity becomes invisible. This makes the budget manhours parameter is the most ideal parameter affecting the objective function and decision variables.

Table 4. Sensitivity Analysis Result.

No	Variable	Variable Change	Maintenance cost	Downtime	Preventive maintenance	Plan Maintenance	Unplan maintenance
1	Cost per hour	Up	Up	Fixed	Fixed	Fixed	Fixed
		Down	Down	Fixed	Fixed	Fixed	Fixed
2	Maintenance Cost Budget	Up	Fixed	Fixed	Fixed	Fixed	Fixed
		Down	Fixed	Fixed	Fixed	Fixed	Fixed
3	Downtime Budget	Up	Fixed	Fixed	Fixed	Fixed	Fixed
		Down	Fixed	Fixed	Fixed	Fixed	Fixed
4	Manhours Budget	Up	Down	Fixed	Up	Down	Fixed
		Down	Up	Fixed	Down	Up	Fixed
5	Actual manpower	Up	Up	Fixed	Down	Up	Fixed
		Down	Down	Fixed	Up	Down	Fixed

The results of this paper compare to actual and budget performance shown in Table 5.

Table 5. Comparison of actual, budget and linear programming calculation (optimation).

Variable	Budget	Actual	Optimation
Maintenance Cost	$ 5,926,507	$ 7,105,137	$ 5,575,781
Downtime	36,816 hr	39,025 hr	29,453 hr
Physical Availability	85%	79%	91.53%
Dozer Production	33,901,676 M^3/year	31,867,575 M^3/year	36,506,123 M^3/year

5. Conclusion

In this paper, we presented a maintenance strategy problem from a case study organization where define dozer performance by history is being operated. The two objective functions considered in the mathematical model formulation of maintenance strategy problem are: (a) minimize the maintenance cost (Z_1) and (b) minimize the downtime (Z_2) after that calculate the production. This Linear programming model has been solved using LINGO solver. The model-1, with objective function-1 and 8 constraints was solved, optimal solution is recorded. For model-2, objective function-2 with 8 constraints has been solved to get optimal solution at stage-2. Production capacity has been counted based on model-1 and model-2 result. This final solution was validated by comparing with the observed values of the company for 3 years. This validated model is useful for the company to derive suitable maintenance strategy and production plans. Companies can choose the maintenance strategy that will be applied by knowing the consequences of each strategy decision chosen. The detail of results are:

a. To get optimum maintenance costs and optimum maintenance, the composition of the maintenance strategy used is 86% downtime preventive maintenance, 14% planned maintenance and 0% unplanned maintenance from total downtime maintenance.
b. From the results of modelling the two objective functions, the results are better than the budget and actual. There is a potential maintenance cost savings of 5.92% against the budget or 21.52% of the actual costs, while for downtime there is a decrease in downtime by 20.00% against the budget or 25.38% of the actual maintenance downtime.
c. There is a potential increase in physical availability of dozers by 6.53% against the budget and 12.53% to the actual, while for the optimization of production planning there is a potential increase in Dozer production capacity by 7.68% to the budget and 14.56% to the actual.
d. The results of the sensitivity analysis show that the parameters whose changes are sensitive to the objective function and decision variables are budget manhours and actual manpower. The greater the value of the budget manhours, the maintenance cost will go down, and the decision variable X_1 (Preventive maintenance) is greater than X_2 (Plan maintenance). The critical point is -19%. As for the actual manpower parameters, the greater the actual value of the manpower, the maintenance cost will increase, and the decision variable X_1 (Preventive maintenance) is greater than X_2 (Plan maintenance). The critical point is 24%.

References

Bouslah, B., Gharbi, A., and Pellerin, R., Joint production, quality and maintenance control of a two-machine line subject to operation-dependent and quality-dependent failures, *International Journal of Production Economics*, vol. 195, pp 210-226, 2018.

Chan, G. K., *Preventive Maintenance With Markov Processes* (unpublished), University of Nebraska, Lincoln, 1998.

Dekker, R., Applications of maintenance optimization models: a review and analysis, *Reliability Engineering & System Safety*, vol. 51, no. 3, pp. 229-240, 1996.

Dunn, S., *Maintenance Conf Proc*, Queensland, Australia, 1998.

Endrenyi, J., Aboresheid, S., Allan, R. N., Anders, G. J., Asgarpoor, S., Billinton, R., et al, The present status of maintenance strategies and the impact of maintenance on reliability. *IEEE Transactions on Power Systems*, vol. 16, no. 4, pp. 638-646, 2001.

Endrenyi, J., Anders, G. J., and Leite da Silva, A. M., Probabilistic evaluation of the effect of maintenance on reliability. An application [to power systems], *IEEE Transactions on Power Systems*, vol. 13, no. 2, pp. 576-583, 1998.

Levitt, J., *Managing Factory Maintenance*, 2nd ed., Industrial Press Inc, New York, 1996.

Levitt, J., *The Handbook of Maintenance Management*, 2nd. ed., Industrial Press Inc, New York, 2009.

Niebel, B. W., *Engineering Maintenance Management*, 2nd ed., CRC Press, Boca Raton, 1994.

Van Horenbeek, A., Pintelon, L., and Muchiri, P., Maintenance optimization models and criteria, *International Journal of System Assurance Engineering and Management*, vol. 1, no. 3, pp. 189-200, 2010.

Xiao, L., Song, S., Chen, X., and Coit, D. W., Joint optimization of production scheduling and machine group preventive maintenance, *Reliability Engineering & System Safety*, vol. 146, pp. 68-78, 2016.